ABSORPTION LINES IN THE GRAVITATIONAL LENS SYSTEM MG 0414+0534

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ABSTRACT

Spectra of components A1 + A2 and B of the gravitational lens system MG0414+0534 taken with the Low Resolution Imaging Spectrograph (LRIS) on the Keck 10 m telescope show that the strong absorption feature seen in a low resolution spectrum is due to a complex of Fe II lines at redshifts near that of the lensed quasar. The redshift of the lens remains unknown.

Subject headings: gravitational lenses – quasars – radio sources: spectra – galaxies: interstellar matter

1. INTRODUCTION

The gravitational lens system MG 0414+0534 (Hewitt *et* al. 1992) is remarkable for its unique optical/infrared spectrum, the wavelength dependence of the flux ratios of the components, and the strength of the absorption feature observed near 8660 Å in a low resolution spectrum. In a companion paper (Lawrence *et al.* 1995a, this volume) we report a redshift of 2.639 for the background quasar. If the absorption feature observed near 8660 Å were intrinsic to the quasar, its rest wavelength would be about 2380 Å. Although Fe II absorption features near this wavelength are often seen in quasar spectra, their equivalent width is usually much smaller than observed in MG 0414+0534. Moreover, the 2″ angular size of MG 0414+0534 means that light from the quasar passes through the lens itself. It seemed to us likely, therefore, that the absorption feature came from the lens, and that an unambiguous identification of the feature would give the lens redshift.

Accordingly, spectra of MG 0414+0534 at a resolution of 2.0 Å (FWHM) were taken with the W. M. Keck 10 m telescope on 1993 October 22 during an early engineering run of the Low Resolution Imaging Spectrograph (LRIS; see Oke *et* al. 1994 and *Cohen et al.* 1994 for details). The slit was oriented to cover both A1+A2 and B.

Early problems with the LRIS readout electronics resulted in very high readout noise and a time-dependent bias level with strong non-random features that could be removed only partially. Nevertheless, a strong absorption doublet was seen near 8650 Å in both A1+A2 and B, with separation exactly as expected for Na I λλ5889.95,5895.92 at a redshift of 0.47. A third absorption feature near 8515 Å was unidentified, although not attributable to any obvious instrumental or night sky problem. We were sufficiently confident of the identification to submit a manuscript claiming that we had measured the redshift of the lens, but nevertheless reobserved MG 0414+0534 with LRIS after the readout problems were corrected. In this paper we report on the new observations, which have a SNR. more than three times higher than the earlier ones, and which require a completely different interpretation of the absorption seen in this interesting lens system.

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2. OBSERVATIONS AND DATA REDUCTION

MG 0414+0534 was reobserved with the Keck 10 m telescope on 1994 November 7, using tile Low Resolution Imaging Spectrograph. The detector is a 2048 x 2048 thinned 'Tektronix CCD, with a peak quantum efficiency at 6500 Å of 80%. A slit 3' long illuminates an area of about 2048 x 800 pixels. The blue- and red-wavelength halves of the chip are read out through independent electronics.

A 1200 line mm^{-1} grating blazed at 7500 Å was used with a 1" slit, giving a FWHM of arc lines and unresolved night sky lines of 2.0 Å. The grating tilt put the wavelength range 80009200 Å on the detector. The overall throughput of the detector, spectrograph, and telescope was about 22% over this range.

The slit was rotated so that components Al + A2 (separated by 0.''41; Katz & Hewitt 1993) and B could be observed simultaneously. Two consecutive 3000s exposures were made, followed by a dome flat and a neon discharge tube exposure, all with the telescope pointed at MG 0414+ 0534. The dAO star GD191B2B (Oke 1990) was observed with the same grating tilt for calibration.

Following bias-subtraction and an adjustment for slightly different gains in the two sets of readout electronics, the flat frame was high-pass filtered, adjusted to have a mean value of unity, and used to flatten the object and arc frames.

Sky emission was subtracted using 3nd order polynomial fits to sky regions roughly 100 pixels wide on both sides of MG 0414+ 0534. Many combinations of polynomial order and region fit were tried both in order to establish the optimum method of sky subtraction, and to get an idea of the uncertainty in the absorption profile due to sky subtraction itself.

The profile of the spectrum of Al +A2 along the slit was wider than that of B, as expected from the 0.''32 projected separation of A1 and A2 along the slit. The entire profile is well-fit by three Gaussians whose widths are equal to that of B, with separations as expected from the radio image. The width of B was 3.5 pixels (0.''80) in the first of the two 3000s exposures and 5.0 pixels (1.''14)in the second. The difference in the widths between the two exposures is due in part to the fact that the second exposure was observed at higher airmass (1 .22- 1.45, compared to 1.091.22 for the first). Even in the second exposure, however, the overlap of Al +A2 and B represents less than 5% of the total energy observed, and the spectra of A1+A2 and B were extracted separately using an optimal extraction routine.

Sixteen lines identified in the Ne spectrum were used to establish the wavelength scale. The rms error in the fitted dispersion relation was 0.03 Å. Offsets between the wavelength scales of the arc spectrum and the MG 0414+ 0534 spectra due to flexure in the spectrograph were determined and removed using the positions of 40 night sky lines. The residual wavelength error on the night sky lines was 0.05 Å.

Corrections for atmospheric extinction and instrumental response were determined from the spectrum of the standard star GD191B2B, observed at the same grating angle. Spectra of A 1 +A2 and B from the two exposures were then averaged. Figure 1 shows the resulting calibrated spectra over the wavelength region where features were detected. The error spectra reflect only photon noise and the random component of readout noise.

3. DISCUSSION

The absorption feature seen in the 4-Shooter spectrum of Hewitt *et al.* (1992) is revealed in Figure 1 to be a blend of many features. Other features arc seen between 8500 and 8550 Å. Fits to these features arc shown in Figure 2. The lines are fitted beautifully by four sets of

ABSORPTION LINES IN MG0414+ 0534

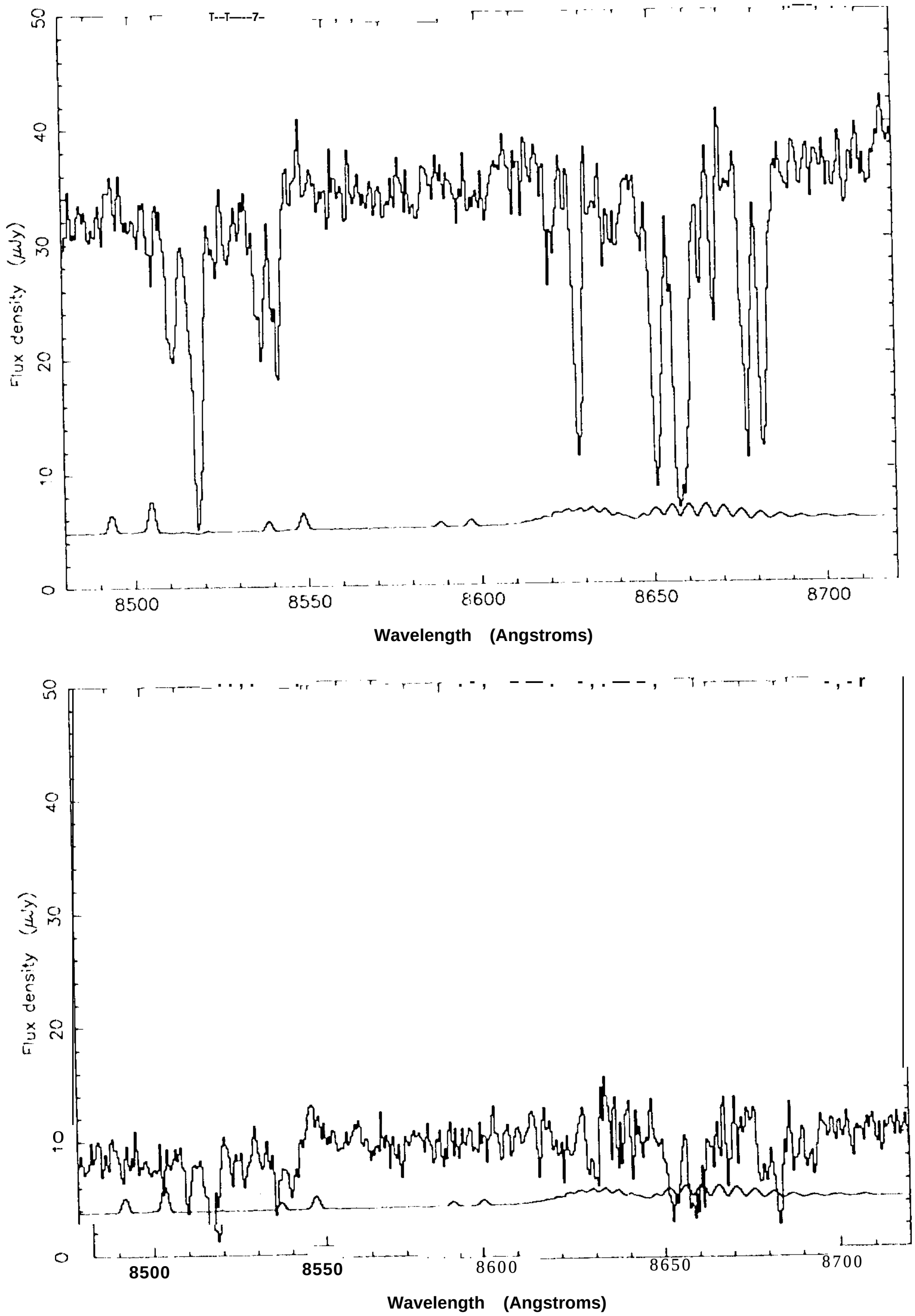

FIG 1.— **Spectra** of MG 0414+ 0534 A1+A2 (upper *panel*) **and** B (*lower panel*) in the region near the absorption feature. Error spectra **at** the bottom of each panel are based on photon noise and random readout noise; the features reflect higher photon noise in night sky lines.

three Fe II lines (rest wavelengths of 2343.495, 2373.737, and 2382.039 Å). Parameters of the fits arc given in Table 1. All wavelengths are heliocentric, in air. The central wavelengths of the lines in each set were constrained to be in the ratio 2343.495 :2373.737:2382.039. One of the 2373.737 lines coincides with the lowest-redshift 2343.495 line, so its amplitude and width were fixed to equal those of the 2373.737 line seen near 8647 Å. Fits were also made with the line centers free to move independently. The rms differences between the constrained and unconstrained centers is only 0.16 Å in Al -I A2 and 0.36 Å in B. These small changes are a convincing demonstration of the line identifications, and can be taken as an estimate of the uncertainties in the line centers.

TABLE 1

ABSORPTION FEATURES OF MG 0414+ 0534 A and B

Name	Center (A)	A mpl. (μJy)	FWHM (A)	W_{obs} (A)
A				
Fe II λ2343.495	.S511 .32	-13.1	3.6	1.5
. . . .	8518.70	- 26.6	4.0	3.4
. . . .	8537.01	-11.9	3.5	1.3
. . . .	8541.83	- 14.5	2.5	1.2
Fe II λ2373.737	8621.12	−6.4	2.4	0.5
. . . .	8628.60	-24.6	2.4	1.8
	8647.14	-5.5	2.0	0.3
. . . .	8652.03	-5.5	2,0	0.3
Fe II λ2382.039	8651.34	-23.6	3.2	2.2
. . .	8658.84	-30.2	5.2	4.7
	8677.45	-23.3	2.7	1.9
	8682.35	-24.6	2.7	2.0
B				
Fe II λ2343.495	8511.87	-5.0	2.0	1.2
. . . .	8518.59	-7.3	3.8	3.3
	8537.74	-4.9	2.2	1.2
. . . . . .	8542.05	-4.0	3.1	1.4
Fe II λ2373.737	8621.68	- 1.7	4.2	0.8
	8628.49	−3.5	2.4	0.9
. . . .	8647.88	-0.6	2.0	0.1
. . . . . .	8652.24	- 0.6	2.0	0.1
Fe II λ2382.039	8651.89	-6.6	3.6	2.5
. . . .	8658.73	-7.0	4.6	3.4
. . . . . .	S678.19	−4.6	3.0	1.4
. . . .	8682,57	-7.7	2.4	1.9

Uncertainties in the amplitudes arc about 2 μK, with corresponding uncertainties in the equivalent widths of 10% in A1+ A2 and 20% in B. The stronger features are saturated, so the ratios of amplitudes among the four systems vary considerably. Many of the lines are resolved (recall that the width of night sky lines is 2.o Å), with corresponding velocities at half maximum up to 170 kms- ^{1}.

'l'he redshifts of the four systems arc '2.63172, 2.63487, 2.64268, and 2.64474. We estimate an uncertainty of $\pm$0.00005 by adding the aforementioned rms differences of 0.16 Å and 0.36 Å in quadrature. Referenced to the lowest redshift system these redshifts correspond to velocity differences are O, 170, 800, and 1070 kms- ^{1}. The redshift of the quasar is given

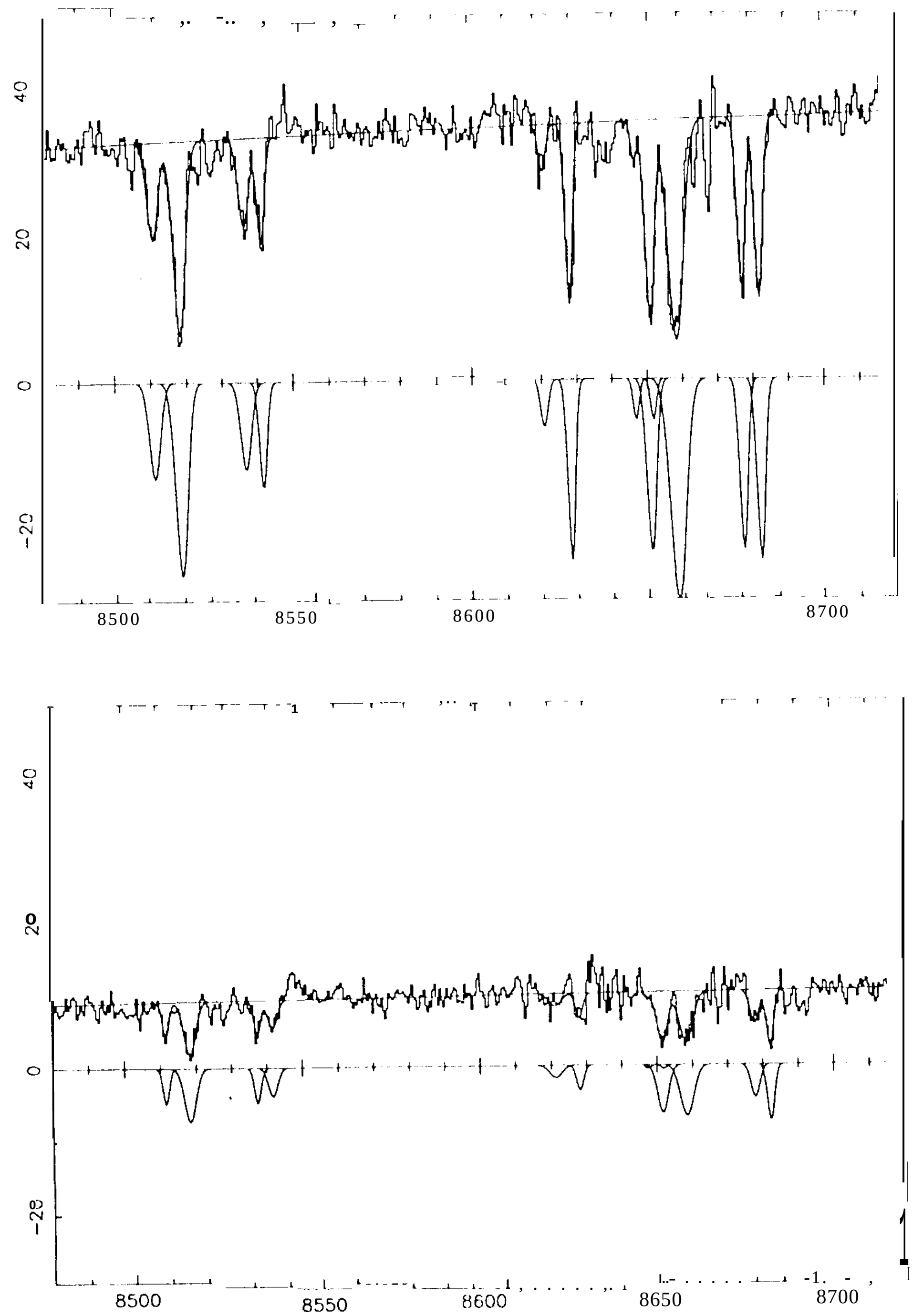

FIG 2.- Absorption features in A1+A2 *(upper panel)* and B *(lower panel)*. The smooth curves are a polynomial fitted to the continuum plus Gaussians fitted to individual features.

by Lawrence *et al.* (this volume) as 2.639 ± 0.002, in mild conflict (given the uncertainties) with absorption at z =- 2.64268 or 2.64474. It is clear that the Fe II absorbers lie close to the quasar, but given the difficulty of determining an accurate redshift from a line as broad at Hα in MG 0414+0534 it will be hard to say exactly how close, The fact that there are four absorbing systems so close to the quasar along a single line of sight, separated by hundreds of kilometers per second, suggests that the quasar lies in a rich environment.

The wavelength differences between the line centers of the four triplets in A and B are probably not significant.

The equivalent widths of the lines are large, particularly in the second-lowest redshift system. The observed equivalent width determined from the low-resolution 4-Shooter spectrum in Hewitt *et* al. (1992) was 20.8 Å, while the total observed W_{eq} for the lines for image A1+ A2 between 8620 and 8683A (which give rise to the absorption feature in the 4-Shooter spectrum) in Table 1 is *13.8* Å. The differences arc almost certainly the result of the low resolution of the 4-Shooter spectrum (FWHM = 27 Å), coupled with the night sky features. Direct comparison of the 4-Shooter and Keck spectra shows that there is no offset in the wavelength scales, but that the shape of the absorption feature in the 4-Shooter spectrum is distorted in a pattern similar to the envelope of the night sky lines in that wavelength range.

The largest rest equivalent width for Fe II λ2382.039 seen in a sample of 103 low and intermediate redshift quasars by Steidel & Sargent (1990) was 2.33 Å in Q 001 3–0029. The sum of the rest equivalent widths of five Fe II lines at z ≈ 1.97 in Q 0013–0029 is 6.81 Å. In MG 04] 4-t 0534 A1+ A2 and B the largest rest equivalent widths seen are 1.29 Å and 0.94 Å, respectively. The sum of the rest equivalent widths for all twelve features is 6.08 Å in A1+A2 and 5.01 Å in B. Thus the iron absorption in MG 0414-t 0534 is unusual but not unprecedented.

The reader is referred to Lawrence *et* al. (1995) for more details on this interesting system, and on the significance of dusty gravitational lenses.

This work is based on observations made at the W. M. Keck observatory, jointly operated by the California Institute of Technology and the University of California. We are grateful to the Keck Foundation for its vision and generosity in support of astronomy. We thank D. Womble and W. Sargent for useful discussions.

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